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RESEARCH MEMORANDUM

EFFECTS OF MOLDING CONDITIONS ON SOME PHYSICAL PROPERTIES OF GLASS-FABRIC UNSATURATED-POLYESTER LAMINATES

By John E. Wier, Dorothy C. Pons, and Benjamin M. Axilrod

National Bureau of Standards

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EFFECTS OF MOLDING CONDITIONS ON SOME PHYSICAL PROPERTIES OF GLASS-FABRIC UNSATURATED-POLYESTER LAMINATES

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SUMMARY

The effects of several molding conditions upon some physical properties of laminates prepared with Fiberglas 181 glass fabric and Bakelite XRS-81 unsaturated-polyester resin were investigated. The molding variables included pressure, temperature, and time during both precuring and curing operations. Molding pressure was varied from 0.02 to 10.0 psi; molding temperature from 120° to 290° F; and molding time from 20 minutes to 48 hours.

The laminates were tested for several physical properties which included resin content, percentage of voids, specific gravity, and flexural strength on the diagonal, both wet and dry.

The flexural strength, resin content, and specific gravity were changed considerably by variation in precure pressure.

The effect of increasing the precure temperature from 210° F, the recommended value for this resin, to 260° F for precure times of 5 to 20 minutes was to reduce the flexural strengths about 25 percent. While precures at 160° F for the same periods of time also resulted in weaker laminates, the strength increased with precure time. Thus, for a precure time of 30 minutes the strengths obtained equalled those for 210° F, and a 48-hour cure at 160° F resulted in laminates about 20 percent stronger than those molded at the recommended conditions.

The resin content varied from about 44 to 49 percent for the various precure cycles. The amount of voids was somewhat erratic but the panels precured at 160° F for 20 minutes or longer had uniformly low amounts of voids.

The effect of varying the cure temperature between 250° and 290° F and the time between 10 and 30 minutes (the recommended values are 270° F and 15 min) on the physical properties was negligible.

It was observed that panels cured at 160° F were much more translucent than those cured at higher temperatures. A possible explanation proposed is based on voids caused by minute ruptures due to stresses evoked by shrinkage and differential thermal expansion.

INTRODUCTION

Glass-fabric unsaturated-polyester laminates are of interest to the aircraft industry not only because of their good electrical and strength properties, but also because of the advantages (references 1, 2, and 3) that such laminates offer from the standpoint of ease of production. The promise that this type of material offers along these lines makes it essential that a better understanding of the effect of fabricating variables on the properties of the finished laminate be obtained (references 4 and 5).

In addition to a need for information on the effects of production variables, there is also a need for improved laminates. For example, one of the important aircraft applications of these laminates is in radomes. Such structures, being exposed to the weather, must not be seriously weakened by prolonged exposure to water or high humidity. The unsaturated-polyester laminates have not been completely satisfactory in this regard. To improve the wet strength of the glass-fabric polyester laminates, it is believed essential to obtain stronger bonds between the resin and the fabric. Among the methods by which this might be accomplished are chemical modification of the resin, development of new finishes for the glass fabric, modification of the resin-coating process, and improvements in curing techniques.

The present investigation was undertaken to obtain some information on the effects of fabrication variables and to study various methods of improving the bond between the glass fabric and the resin. This report covers the first phase of this investigation, namely, a study of the effects of variations in molding conditions on the properties of a glass-fabric laminate prepared with a single unsaturated polyester. One of the objectives of this work was to reveal factors that needed to be considered in carrying out other parts of this investigation.

This investigation was conducted at the National Bureau of Standards under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

MATERIALS

The glass fabric selected for this work was Fiberglas 181 with finish No. 114. This fabric was recommended by the manufacturer as the best type for making laminates that would have good strength both dry and after immersion in water.

Fiberglas 181 is an eight-shaft harness-weave fabric. Finish No. 114 is a methacrylic chrome complex (reference 6) designed to make the fabric more water repellent, thus improving the wet strength of the finished laminate. The fabric was furnished in rolls 38 inches wide. Two different rolls of fabric were used. No predetermined sampling methods were employed in selecting the pieces of fabric to be used in any of the laminates.

The resin used was Bakelite XRS-81, an unsaturated-polyester type. It was selected as being a representative product. Only one batch of resin was used for the entire investigation. The catalyst was lauroyl peroxide, Alperox C, in granular form.

The cellophane used as a release agent was Sylphrap, Type No. 600 P-1-L.

DEFINITIONS

Flexural strength S: For a beam of rectangular cross section subjected to a concentrated load at midspan:

$$S = \frac{3}{2}\frac{PL}{bd^2}$$

where

P maximum load

L span or distance between supports

b width of beam

d depth of beam

Specific flexural strength:

$$\frac{S}{(\text{Specific gravity})^2}$$

This ratio compares the flexural strengths of different materials when their densities are taken into account. If the weight, span, and width of a given beam are fixed and if the beam is made of different materials the breaking loads are proportional to this ratio.

Resin content: Amount by weight of resin in the laminate.

Percentage of voids: Estimated volume of voids V_v in a specimen expressed in percentage of the measured volume V_s of the specimen:

$$V_v = V_s - V_s'$$

where

V_s volume of specimen obtained by weighing in water and in air

V_s' volume of specimen calculated on the assumption of no voids and using the measured weight of the resin and of the glass fabric in the specimen and known values for the density of the glass fabric and resin.

Coefficient of variation C_v:

$$C_v \text{ in percent} = \frac{\sqrt{\frac{\sum (x_i - \bar{x})^2}{N - 1}}}{\bar{x}} 100$$

where

x_i i^{th} measurement

$\bar{x}$ arithmetic mean

N number of measurements

PROCEDURES AND EQUIPMENT

Fabrication of Laminates

Preparation of glass fabric.- The fabric was cut into pieces 6.5 inches square. To keep the fibers of the fabric from unweaving during the impregnation process, the edges of each piece of fabric were coated with starch. The pieces of fabric were then conditioned at 77° F and 50-percent relative humidity for at least 72 hours prior to resin impregnation.

Preparation of resin.- The resin, Bakelite XRS-81, was mixed with 1 percent by weight of the catalyst in batches of 400 to 500 grams. The mixture of resin and catalyst was stirred for a period of 1 hour with an electrically powered propeller-type stirrer. To minimize the escape of the more volatile components of the resin, the mixing jar was covered almost completely during the stirring.

Impregnation of fabric with resin.- The fabric was impregnated with resin by running it through a pair of hand-operated squeeze rollers which were kept coated with resin. Each square of fabric was run between the rollers as many times as were required for the fabric to lose its opacity. Uniform translucency of the fabric was considered to be the criterion of sufficient impregnation.

Panel assembly.- A piece of cellophane was laid on a flat surface and a small amount of resin was spread over an area of the same size as the squares of fabric. A square of resin-impregnated fabric was then placed over the area. Care was taken not to trap large amounts of air between the cellophane and the fabric. Any air pockets formed were eliminated by stroking the surface of the fabric with a spatula. In this operation great care was exercised to prevent undue scratching of the fibers or crimping of the material; the direction of motion was always parallel to the top fibers of the fabric.

In assembling the laminate a small amount of resin was poured over the top of each ply. This excess resin not only facilitated the elimination of the air pockets, but also insured a sufficiency of resin in the finished product.

After seven plies had been laid up in this manner, another piece of cellophane was placed over the top of the assembled plies. Elimination of air pockets was again accomplished by passing a spatula over the cellophane on each side of the lay-up. The ends of the cellophane sheets, which extended beyond the limits of the laminate, were then folded over and held in place with paper clips. The cellophane-wrapped lay-up was placed between preheated glass plates and the assembly placed in a laminating press. After completion of the desired molding cycle, the laminate was removed from the press while hot.

Molding conditions.- Duplicate panels were made under 25 different combinations of molding variables.

To determine the effect of pressure variation, panels were molded at five different pressures, ranging from 0.02 to 10 psi. Two pressure cycles were used. In one cycle the precure pressure was kept equal to the cure pressure. In the other, only the precure pressure was varied, while the cure pressure was kept constant at 10 psi. The precure cycle was kept constant at 210° F for 10 minutes and the cure cycle at 270° F

for 20 minutes. This molding cycle is the one recommended for this resin by the manufacturer except that the cure time is 5 minutes longer than recommended.

To determine the effects of variations in the precure temperature and time, laminates were molded with the following precure cycles: (a) 160° F for 5, 10, 20, and 30 minutes and (b) 210° and 260° F for 5, 10, and 20 minutes. The cure cycle was kept constant at 270° F for 20 minutes. In addition, two panels were cured at 120° F and two at 160° F for periods of 48 hours, with no other precure and with the higher temperature cure cycle eliminated. The molding pressure was kept constant at 0.7 psi in this series of tests.

To determine the effects of variation in the cure cycle, the following temperature-time combinations were investigated: (a) 250° and 290° F for periods of 10 and 20 minutes and (b) 270° F for 20 minutes. The precure cycle was kept constant at 210° F for 10 minutes. The molding pressure was kept constant at 0.7 psi.

Operation and regulation of the press.- The press used was a 10-ton hand-operated Carver laminating press, Model No. 126, equipped with steam-heated platens and a steam-pressure control valve to regulate the temperature. Temperatures were checked with a mercury thermometer placed in a well in one platen and were maintained to ±1° C.

Pressures up to and including 2.0 psi were maintained by the use of dead weights. Pressures over 2.0 psi were obtained by the use of the hydraulic mechanism of the press. These latter pressures probably varied by as much as 1 psi since their control and maintenance were manual.

Testing of Laminates

Conditioning of specimens prior to testing.- All specimens were conditioned for a minimum of 7 days at a temperature of 77° F and 50-percent relative humidity prior to testing.

Flexure tests.- The flexure specimens were cut to a length of 2 to 2.5 inches, depending on the thickness of the laminate, and were oriented in the 45° diagonal direction. These specimens were machined by dry grinding to a width of 0.500 ± 0.005 inch. The thickness was that of the laminate which varied between 0.06 and 0.13 inch. Thicknesses were measured to ±0.0002 inch.

The tests were made on two Baldwin-Southwark universal hydraulic testing machines of the fluid-support Bourdon-tube type. The machines, which had capacities of 2,400 and 60,000 pounds, respectively, each had a 240-pound lowest range; the latter range was accurate to within

1 percent at the loads encountered and was used for all tests. Each machine was located in a room controlled at 77° F and 50-percent relative humidity.

A variable-span flexure jig was used for testing the specimen as a simple beam loaded at midspan. The contact edges of the supports and the pressure piece were rounded to a radius of 1/32 of an inch. In testing, the span-depth ratio was set at 16 to 1 with the span controlled to ±0.001 inch. The speed of testing was in accordance with the formula in method 1031 of reference 7.

Twelve specimens from each panel were tested in the manner described, half of them after conditioning for 7 days at 77° F and 50-percent relative humidity and half after 7 days' immersion in water.

Specific gravity.- Specific gravity was measured on the flexure specimens by the displacement-of-water technique according to method 5011 of reference 7. An analytical balance was used in weighing the specimens both in air and in water.

Resin content.- The resin content was obtained as follows: For the initial weight of the specimen, the value obtained in determining the specific gravity was used. The specimen, after being tested for flexural strength, was heated for 2 hours at 800° to 900° F in a muffle furnace to remove the resin and fabric sizing. After cooling, the residue of the specimen, that is, the glass fabric remaining, was weighed. The weight of residue was divided by the factor 0.997 to correct for the sizing removed, the corrected value being the initial weight of the glass fabric in the specimen. The factor 0.997 was obtained by comparing the weight of a sample of conditioned glass fabric with the weight of the same sample after being heated similarly to the specimens. The amount by weight of resin in the specimen was taken as the difference between the initial weight of the specimens and the initial weight of the glass fabric in the specimens.

Percentage of voids.- The percentage of voids in a specimen was determined as follows: The volume V_s of the specimen (see definitions) was calculated from the weight of the specimen in air and in water, determined previously (see section on specific gravity). The volume of resin in the specimen was computed using a value of 1.21 for the specific gravity of the resin. This value was determined experimentally on 10 specimens of pure resin according to method 5011 of reference 7. The volume of glass in the specimen was computed from its initial weight and specific gravity. The value for the specific gravity of the glass was taken as 2.51.

RESULTS AND DISCUSSION

The data obtained on panels molded at different pressures are shown in tables I and II and in figures 1 to 4. The results obtained on panels molded with various precure conditions are shown in tables III and IV and figure 5. Tables V and VI contain the data for panels molded under different cure conditions.

Since the data given are based on a relatively small number of specimens taken from each panel and since the coefficients of variation appear to be unaffected by changes in molding conditions, the average of the coefficients of variation of each property for all panels may be used as a measure of the precision of the results. These averages of the coefficients of variation of each property for all panels were as follows:

Property	Average C_v (percent)
Flexural strength, dry	4.8
Flexural strength, wet	5.2
Resin content	2.7
Specific gravity	1.1
Voids	6.9

Effects of Variations in Pressure

Statistical analysis of the data[1] (tables I and II) revealed no significant differences between the properties of laminates molded at the two pressure cycles. It can be concluded that all the effects of variations in pressure on these physical properties of the laminates occur in the precure stage of the molding cycle. Variations in pressure after the precure have little if any effect on the finished laminate. The values mentioned in the following discussion of effects of variations in molding pressure are average values for the panels molded under both pressure cycles.

An increase in molding pressure during the precure stage from 0.02 to 10.0 psi results in large increases in flexural strength, both dry and wet (table I and fig. 1), in large increases in specific gravity (table II and fig. 2), and in large decreases in resin content (table II and fig. 3). Dry diagonal flexural strength increased from 15,900 psi for specimens molded at 0.02-psi pressure to 27,400 psi for specimens molded at 10-psi pressure. The corresponding values for wet flexural strength were 11,500 and 18,800 psi, respectively.

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[1]The assistance of Mr. J. Mandel who made the statistical analysis is appreciated.

The percentage loss in strength due to water immersion ranged from 26 to 32 percent. No trend in percentage loss in strength is in evidence in respect to molding pressure.

Specific flexural strength varied between 6700 and 7900 psi. The correlation between specific flexural strength and molding pressure is poor.

The specific gravities (table II and fig. 2) of the laminates increased from 1.51 to 1.87 as the molding pressure during the precure stage increased from 0.02 to 10.0 psi. For this change in pressure the resin content of these laminates (table II and fig. 3) diminished from 53 to 31 percent. The percentage of voids (table II) decreased from 5.4 percent at 0.02 psi to 1.0 percent at 10-psi pressure. Some deviations from this general trend in the amount of voids are in evidence, especially in the case of one of the panels molded at 0.02 psi, which had only 1.6 percent voids. From this it must be inferred that while an increase in molding pressure tends to decrease the volume of voids, there may be other molding variables which affect the volume of voids in the finished laminate.

The correlation between resin content and flexural strength is shown in figure 4. Flexural strength increased from 15,900 psi in panels with a resin content of 53 percent to 27,400 psi in panels with a resin content of 31 percent. Effects of voids are not considered in this graph.

Effects of Variations in Precure Temperature and Time

The dry flexural strength of panels precured at 160° F (table III and fig. 5) increased with an increase in the time of the precure cycle, the values ranging from 10,200 psi for the 5-minute precure to 19,500 psi for the 30-minute precure. When the molding period at this temperature was extended to 48 hours, the strength of the panels increased to 23,800 psi. This value is higher than any obtained under any of the other molding conditions of time, temperature, and identical pressure (0.7 psi).

The dry flexural strength of panels precured at 210° F, the precure temperature recommended for this resin by the manufacturer, did not vary markedly between panels cured for periods of 5 to 20 minutes, inclusive; their strength was about 20,000 psi. This is higher than the flexural strengths obtained for panels precured at temperatures of 160° and 260° F for similar periods. For laminates precured at 260° F for periods of 5 to 20 minutes, inclusive, the flexural strengths were 12,000 to 14,500 psi.

The variation of the wet strength of the panels with precure time and temperature was similar to that for dry flexural strength, the loss

in strength due to immersion being 23 to 35 percent. Panels molded for 48 hours at 160° F without any additional cure at a higher temperature had a higher wet flexural strength, 16,000 psi, than panels cured at any of the other molding cycles.

The variation of the specific flexural strength of the panels with precure time and temperature is similar to the behavior of the dry flexural strength. Thus, panels precured at 160° F increased from 4400 to 7000 psi in specific strength with an increase in precure time from 5 to 30 minutes. Panels cured for 48 hours at 160° F had an average specific strength of 8700 psi, higher than that for any other condition.

Laminates precured at 210° F for various periods had average specific strengths of 7300 to 7600 psi, while those precured at 260° F for similar periods averaged between 5000 and 5600 psi.

The specific gravity and resin content did not vary greatly with precure temperature and time. The specific gravity of panels precured at 160° F for 5 minutes and for all three precure periods at 260° F was 1.60 or less. Panels precured at the other molding conditions had specific gravities of more than 1.64.

Resin content was between 44 and 47 percent in all panels precured at 160° F for periods of 10 minutes or longer, and 210° F for all periods. Average resin content of panels precured at 160° F for 5 minutes was 41.5 percent. Panels precured at 260° F ranged between 47 and 49 percent in resin content.

The data on voids are somewhat erratic; in particular, the values on duplicate panels did not agree as well as expected. It is noted, however, that the average amount of voids was only about 1 percent for panels precured 20 minutes or more at 160° F. The problem of voids is considered in the section Causes and Effects of Voids.

Effects of Variations in Cure Temperature and Time

Examination of the data (tables V and VI) obtained on panels cured at 250°, 270°, and 290° F for 10 to 30 minutes, inclusive, reveals no appreciable differences in the properties of the laminates prepared at these different curing conditions.

Causes and Effects of Voids

It has been shown in an investigation similar to this one that there is some relation between voids and strength for cotton-filled phenolics (reference 5). In view of this, it is reasonable to expect that voids have some effect on the properties of glass-fabric laminates.

The effects of voids on flexural strength of this type of laminate are illustrated in figure 6. The flexural strength against the amount of voids is plotted for individual specimens taken from panels precured at 160° F for various periods of time. These particular panels were selected for the reason that they had a greater range of voids than panels precured at any of the other temperatures. It is evident from figure 6 that voids and flexural strength are related to some extent, the flexural strength decreasing with the amount of voids. The scatter of the data in figure 6, especially in laminates of low void content, can be partially attributed to experimental error in the measurement of voids. Furthermore, it is believed that there are several types of voids and that these different types of voids do not affect the flexural strength in the same manner.

These different types of voids could be caused by (a) air, (b) water vapor, (c) vapors of some of the more volatile constituents of the resin employed, and (d) a combination of any or all of these. There is little doubt that some air is trapped when the laminate is assembled under ordinary atmospheric conditions. Some water vapor will also be included along with the air. Since the glass fabric is slightly hygroscopic, it will also pick up some moisture from the air during the resin-coating process.

The voids data on panels precured at high temperatures indicate a high percentage of voids in laminates cured at these temperatures. This suggests that at these molding temperatures some of the styrene monomer in the Bakelite XRS-81 resin may be volatilized before the cure is complete.

Another aspect of voids which bears consideration is their position within the laminate. A void could be intraresinous, that is, wholly surrounded by resin, or interfacial, that is, between the glass fiber and the resin.

It is possible that the effect of voids upon the strength properties of the laminate may be related to both the chemical composition of the vapor causing them and their location in respect to the components of the laminate. Thus, an air void may act as an inhibitor[2] of cure of the resin immediately surrounding it and thus create a soft, undercured region in the vicinity of the void; a number of such regions should considerably weaken the laminate. On the other hand, if the void is composed of resin vapors, it will not affect the cure of the surrounding resin. With regard to location, if the void is intraresinous, the specific flexural strength of the laminate may actually be increased because of a decrease in its density without a corresponding loss in its strength.

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[2]It is known that the cure of a number of unsaturated-polyester resins is inhibited by air.

The interfacial voids may arise from different sources, such as incomplete wetting of the glass fibers by the resin or local minute ruptures of the resin-fiber bonds either during or subsequent to the molding cycle. These ruptures of the bond may be caused by a combination of shrinkage of resin due to cure and differential thermal expansion of the glass fibers and the resin (reference 8).

Experimental evidence gives some support to these hypotheses concerning the causes of interfacial voids. It was observed that laminates molded at the lower temperatures, such as 160° F, have a higher translucency than the laminates cured at higher temperatures. It is logical to assume that this translucency is an indication of a greatly reduced amount of voids at the resin-fiber interface.

A partial explanation of the higher translucency of panels cured at the low temperatures may be that at these temperatures the resin is given a better opportunity to wet the fabric thoroughly. The advantage of a decrease in viscosity as the temperature is increased is offset at high temperatures by the fact that gelation of the resin begins almost immediately. As a result the resin does not have sufficient time to wet the fabric thoroughly.

It has been further observed that the translucency of laminates cured at low temperatures is reduced somewhat by a subsequent cure at the high temperatures, while initial curing of the laminates at high temperatures produced an almost opaque material. This would indicate that the high temperatures tend to accentuate the differential in volume change between the resin and the glass, thus creating additional stresses at the resin-glass interface which might be sufficient to cause numerous minute ruptures of the adhesive bond. Shrinkage stresses may also be greater for higher-temperature cures.

In spite of the poor correlation in the experimental data between percentage of voids and strength, it seems reasonable to seek methods of fabricating laminates which eliminate voids.

SUMMARY OF RESULTS

The effects of molding variables on some physical properties of laminates made with an unsaturated polyester resin, Bakelite XRS-81, and a glass fabric, Fiberglas 181-114, are as follows:

1. An increase in molding pressure from 0.02 to 10 psi had the following effects:

(a) Decreased the resin content; the amount of resin in the finished laminate depended chiefly on the precure pressure rather than on the cure pressure.

(b) Increased the flexural strength

(c) Generally decreased the percentage of voids, although laminates of low void content could be molded at pressures as low as 0.02 psi

(d) Increased the specific gravity

(e) Did not appreciably affect the specific flexural strength

(f) Did not affect the ratio of wet strength to dry strength, the ratio being about 0.65 to 0.75

2. An increase in precure temperature from the 210° F recommended for this resin by the manufacturer to 260° F for precure times of 5 to 20 minutes had the following effects:

(a) Decreased the strength properties of the laminate

(b) Increased the percentage of voids

3. A decrease in the precure temperature to 160° F had the following effects:

(a) Decreased flexural strength for precure times of 5 to 20 minutes, inclusive; the strength obtained with 30-minute precure at 160° F is about equal to that observed for laminates precured at 210° F for 5 to 20 minutes inclusive.

(b) Reduced the voids to a minimum when the precure time was 20 minutes or more

4. Variations in the curing cycle in the range of 10 minutes at 250° F to 30 minutes at 290° F had little effect on the properties investigated.

5. Extending the curing time to 48 hours at a temperature of 160° F improved the strength properties relative to those observed at other cure cycles

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TABLE I.- FLEXURAL STRENGTH PROPERTIES OF GLASS-FABRIC POLYESTER LAMINATES MOLDED AT VARIOUS PRESSURES[1]

Molding pressure (psi)	Diagonal flexural strength values (2)						Average for both pressure cycles
	Pressure cycle A (3)			Pressure cycle B (4)			
	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	
	Flexural strength, dry (psi)						
0.02	15.9×10^3	16.9×10^3	16.4×10^3	13.7×10^3	17.2×10^3	15.5×10^3	15.9×10^3
.7	18.6	19.6	19.1	21.9	19.9	20.9	20.0
2.0	18.6	19.9	19.3	21.8	20.6	21.2	20.2
5.0	24.7	23.8	24.2	21.1	22.4	21.8	23.0
10.0	27.0	27.8	27.4	See pressure cycle A			27.4
	Flexural strength, wet (psi)						
0.02	11.5×10^3	12.1×10^3	11.8×10^3	9.7×10^3	12.6×10^3	11.2×10^3	11.5×10^3
.7	13.6	13.2	13.4	14.3	13.2	13.7	13.6
2.0	13.8	15.4	14.6	15.4	14.8	15.1	14.9
5.0	17.7	16.0	16.9	15.2	15.3	15.3	16.1
10.0	18.6	18.9	18.8	See pressure cycle A			18.8
	Specific flexural strength, dry (psi)						
0.02	7.2×10^3	6.5×10^3	6.9×10^3	6.3×10^3	7.8×10^3	7.1×10^3	7.0×10^3
.7	7.0	7.2	7.1	8.1	7.1	7.6	7.4
2.0	6.1	6.7	6.4	7.2	6.6	6.9	6.7
5.0	7.7	7.4	7.6	6.6	6.8	6.7	7.1
10.0	7.8	7.9	7.9	See pressure cycle A			7.9
	Loss in flexural strength due to water immersion[5] (percent)						
0.02	27.7	28.4	28.1	29.2	26.7	28.0	28.0
.7	26.9	32.6	29.8	34.7	33.7	34.2	32.0
2.0	25.8	22.6	24.2	29.4	28.2	28.8	26.5
5.0	28.3	32.8	30.6	28.0	31.7	29.9	30.2
10.0	31.1	32.0	31.6	See pressure cycle A			31.6

[1]For all panels precure cycle was 10 min at 210° F and cure cycle was 20 min at 270° F.

[2]Each value for a panel is the average for six specimens.

[3]Precure pressure varied as shown in column 1; cure pressure was constant at 10 psi.

[4]Precure and cure pressures are equal; these pressures are given in column 1.

[5]Based on the difference of the averages for six dry and six wet specimens taken from each panel.

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TABLE II.- DENSITY PROPERTIES OF GLASS-FABRIC POLYESTER LAMINATES MOLDED AT VARIOUS PRESSURES[1]

Molding pressure (psi)	Density properties (2)						Average for both pressure cycles
	Pressure cycle A (3)			Pressure cycle B (4)			
	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	
	Specific gravity						
0.02	1.49	1.61	1.55	1.47	1.48	1.48	1.51
.7	1.62	1.64	1.63	1.62	1.67	1.65	1.64
2.0	1.74	1.72	1.73	1.74	1.77	1.75	1.74
5.0	1.80	1.79	1.80	1.79	1.81	1.80	1.80
10.0	1.86	1.87	1.87	See pressure cycle A			1.87
	Resin content (percent by weight)						
0.02	52.3	50.1	51.2	56.9	53.2	55.1	53.1
.7	47.2	45.1	46.2	44.8	45.1	45.0	45.6
2.0	37.1	37.4	37.3	39.5	36.1	37.8	37.5
5.0	33.6	33.3	33.5	37.1	34.0	35.6	34.5
10.0	31.4	30.7	31.1	See pressure cycle A			31.1
	Voids (percent by volume)						
0.02	7.4	1.6	4.5	5.4	7.1	6.3	5.4
.7	2.4	2.9	2.7	4.3	1.0	2.7	2.7
2.0	3.3	3.8	3.6	1.4	2.2	1.8	2.7
5.0	2.3	3.0	2.7	2.0	1.6	1.8	2.2
10.0	.8	1.1	1.0	See pressure cycle A			1.0
	Thickness (in.)						
0.02	0.119	0.104	0.112	0.130	0.120	0.125	0.118
.7	.097	.094	.096	.095	.091	.093	.094
2.0	.077	.078	.078	.079	.073	.076	.077
5.0	.069	.070	.069	.075	.070	.072	.070
10.0	.064	.064	.064	.064	.064	.064	.064

[1]For all panels precure cycle was 10 min at 210° F and cure cycle was 20 min at 270° F.

[2]Each value for a panel is the average for 12 specimens.

[3]Precure pressure varied as shown in column 1; cure pressure constant at 10 psi.

[4]Precure and cure pressures equal; these pressures are given in column 1.

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TABLE III.- FLEXURAL STRENGTH PROPERTIES OF GLASS-FABRIC POLYESTER LAMINATES MOLDED AT VARIOUS PRECURE TEMPERATURES[a]

Precure temperature (°F)	Diagonal flexural strength values (b)														
	Cure cycle kept constant at 270° F for 20 min												No precure; cured for 48 hr at temperature shown		
	5-min precure			10-min precure			20-min precure			30-min precure					
	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average
	Flexural strength, dry (psi)														
120	----	----	----	----	----	----	----	----	----	----	----	----	20.4×10^3	19.9×10^3	20.2×10^3
160	8.4×10^3	12.1×10^3	10.2×10^3	11.7×10^3	14.3×10^3	13.0×10^3	19.6×10^3	17.6×10^3	18.6×10^3	17.5×10^3	21.5×10^3	19.5×10^3	24.7	22.9	23.8
210	19.4	20.1	19.8	[c]21.9	[c]19.9	[c]20.9	21.0	19.8	20.4	----	----	----	----	----	----
260	14.8	11.1	13.0	14.2	14.8	14.5	11.8	12.6	12.2	----	----	----	----	----	----
	Flexural strength, wet (psi)														
120	----	----	----	----	----	----	----	----	----	----	----	----	14.9×10^3	14.7×10^3	14.8×10^3
160	6.2×10^3	8.9×10^3	7.6×10^3	9.1×10^3	10.8×10^3	10.0×10^3	14.0×10^3	12.4×10^3	13.2×10^3	12.5×10^3	14.8×10^3	13.6×10^3	16.8	16.0	16.4
210	14.8	15.0	14.9	[c]14.3	[c]13.2	[c]13.7	15.5	14.2	14.9	----	----	----	----	----	----
260	10.5	7.8	9.2	10.9	11.8	11.4	8.2	9.0	8.6	----	----	----	----	----	----
	Specific flexural strength, dry (psi)														
120	----	----	----	----	----	----	----	----	----	----	----	----	7.3×10^3	7.1×10^3	7.2×10^3
160	3.9×10^3	5.0×10^3	4.4×10^3	4.4×10^3	5.2×10^3	4.8×10^3	7.0×10^3	6.3×10^3	6.6×10^3	6.3×10^3	7.6×10^3	7.0×10^3	9.2	8.2	8.7
210	7.3	7.3	7.3	[c]8.1	[c]7.1	[c]7.6	7.7	7.2	7.5	----	----	----	----	----	----
260	5.7	4.6	5.2	5.5	5.8	5.6	4.9	5.0	5.0	----	----	----	----	----	----
	Loss in flexural strength due to water immersion[d] (percent)														
120	----	----	----	----	----	----	----	----	----	----	----	----	27.0	26.1	26.6
160	26.2	26.4	26.3	22.2	24.5	23.4	28.6	29.5	29.0	28.6	31.2	29.9	32.0	30.1	31.0
210	23.7	25.4	24.6	[c]34.7	[c]33.7	[c]34.2	26.2	28.3	27.3	----	----	----	----	----	----
260	29.0	29.7	29.4	23.2	20.3	21.8	30.5	28.6	29.6	----	----	----	----	----	----

[a]For all panels pressure was 0.7 psi.

[b]Each value for a panel is the average for six specimens.

[c]These values taken from table I for panels made under these molding conditions.

[d]Based on the difference of the averages for six dry and six wet specimens taken from each panel.

TABLE IV.- DENSITY PROPERTIES OF GLASS-FABRIC POLYESTER LAMINATES MOLDED AT VARIOUS PRECURE TEMPERATURES[a]

Precure temperature (°F)	Density properties (b)														
	Cure cycle kept constant at 270° F for 20 min												No precure; cured for 48 hr at temperature shown		
	5-min precure			10-min precure			20-min precure			30-min precure					
	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average
	Specific gravity														
120	----	----	----	-----	-----	-----	----	----	----	----	----	----	1.67	1.67	1.67
160	1.46	1.56	1.51	1.63	1.65	1.64	1.67	1.68	1.67	1.67	1.68	1.67	1.64	1.67	1.65
210	1.63	1.66	1.64	[c]1.62	[c]1.67	[c]1.65	1.66	1.66	1.66	----	----	----	----	----	----
260	1.61	1.55	1.58	1.61	1.60	1.60	1.56	1.58	1.57	----	----	----	----	----	----
	Resin content (percent by weight)														
120	----	----	----	-----	-----	-----	----	----	----	----	----	----	45.6	45.5	45.5
160	40.2	42.9	41.5	43.4	44.9	44.2	45.2	45.2	45.2	45.7	45.2	45.5	47.5	46.3	46.9
210	45.4	45.2	45.3	[c]44.8	[c]45.1	[c]44.9	44.9	45.1	45.0	----	----	----	----	----	----
260	47.6	50.6	49.1	49.0	48.9	48.9	48.2	45.8	47.0	----	----	----	----	----	----
	Voids (percent by volume)														
120	----	---	----	----	----	----	---	---	---	---	---	---	0.7	0.8	0.8
160	17.0	9.4	13.2	4.8	2.7	3.8	0.9	0.9	0.9	0.9	0.7	0.8	1.5	.7	1.1
210	3.7	1.9	2.8	[c]4.3	[c]1.0	[c]2.7	2.2	1.6	1.9	---	---	---	---	---	---
260	2.9	4.8	3.9	2.4	2.7	2.6	6.0	6.4	6.2	---	---	---	---	---	---
	Thickness (in.)														
120	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.091	0.090	0.090
160	0.095	0.094	0.095	0.090	0.092	0.091	0.090	0.091	0.090	0.090	0.090	0.090	.095	.093	.094
210	.093	.091	.092	.095	.091	.093	.090	.090	.090	-----	-----	-----	-----	-----	-----
260	.100	.107	.104	.099	.100	.100	.104	.096	.100	-----	-----	-----	-----	-----	-----

[a]For all panels pressure was 0.7 psi.
[b]Each value for a panel is the average for 12 specimens.
[c]These values taken from table II for panels made under these molding conditions.

TABLE V.- FLEXURAL STRENGTH PROPERTIES OF GLASS-FABRIC POLYESTER LAMINATES MOLDED AT VARIOUS CURING CYCLES[1]

Cure temperature (°F)	Flexural strength values (2)								
	Cure time of 10 min			Cure time of 20 min (3)			Cure time of 30 min		
	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average
	Flexural strength, dry (psi)								
250	20.5×10^3	21.0×10^3	20.8×10^3	----------	----------	----------	20.8×10^3	21.2×10^3	21.0×10^3
270	----------	----------	----------	21.9×10^3	19.9×10^3	20.9×10^3	20.0	19.0	19.5
290	20.7	20.0	20.4	----------	----------	----------	21.0	20.5	20.8
	Flexural strength, wet (psi)								
250	14.5×10^3	15.8×10^3	15.2×10^3	----------	----------	----------	14.4×10^3	15.3×10^3	14.8×10^3
270	----------	----------	----------	14.3×10^3	13.2×10^3	13.7×10^3	13.8	13.9	13.8
290	14.5	14.4	14.4	----------	----------	----------	15.0	14.8	14.9
	Specific flexural strength, dry (psi)								
250	7.4×10^3	7.7×10^3	7.6×10^3	----------	----------	----------	7.5×10^3	7.8×10^3	7.6×10^3
270	----------	----------	----------	8.1×10^3	7.1×10^3	7.6×10^3	7.4	7.2	7.3
290	7.4	7.4	7.4	----------	----------	----------	7.6	7.5	7.6
	Loss in flexural strength due to water immersion[4] (percent)								
250	29.3	24.8	27.0	----	----	----	30.8	27.8	29.3
270	----	----	----	34.7	33.7	34.2	31.0	26.8	28.9
290	30.0	28.0	29.0	----	----	----	28.6	27.8	28.2

[1]For all panels pressure was 0.7 psi and precure cycle was 10 min at 210° F.
[2]Each value for a panel is the average for six specimens.
[3]The values in these three columns are taken from table I for panels made under these molding conditions.
[4]Based on the difference of the averages for six dry and six wet specimens taken from each panel.

TABLE VI.- DENSITY PROPERTIES OF GLASS-FABRIC POLYESTER LAMINATES MOLDED AT VARIOUS CURING CYCLES[1]

Cure temperature (°F)	Density properties (2)								
	Cure time of 10 min			Cure time of 20 min (3)			Cure time of 30 min		
	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average	Panel 1	Panel 2	Average
	Specific gravity								
250	1.66	1.64	1.65	----	----	----	1.67	1.65	1.66
270	----	----	----	1.62	1.67	1.65	1.65	1.63	1.64
290	1.67	1.64	1.65	----	----	----	1.66	1.65	1.66
	Resin content (percent by weight)								
250	45.0	46.6	45.8	----	----	----	45.4	46.1	45.7
270	----	----	----	44.8	45.1	44.9	46.6	47.3	47.0
290	45.6	47.3	46.5	----	----	----	45.7	46.5	46.1
	Voids (percent by volume)								
250	1.9	1.6	1.8	---	---	---	1.2	1.8	1.5
270	---	---	---	4.3	1.0	2.7	1.5	2.1	1.8
290	1.0	1.4	1.2	---	---	---	1.2	1.5	1.4
	Thickness (in.)								
250	0.092	0.092	0.092	-----	-----	-----	0.090	0.093	0.092
270	-----	-----	-----	0.095	0.091	0.093	.094	.095	.094
290	.092	.094	.093	-----	-----	-----	.092	.092	.092

[1]For all panels pressure was 0.7 psi and precure cycle was 10 min at 210° F.

[2]Each value for a panel is the average for 12 specimens.

[3]The values in these three columns are taken from table II for panels made under these molding conditions.

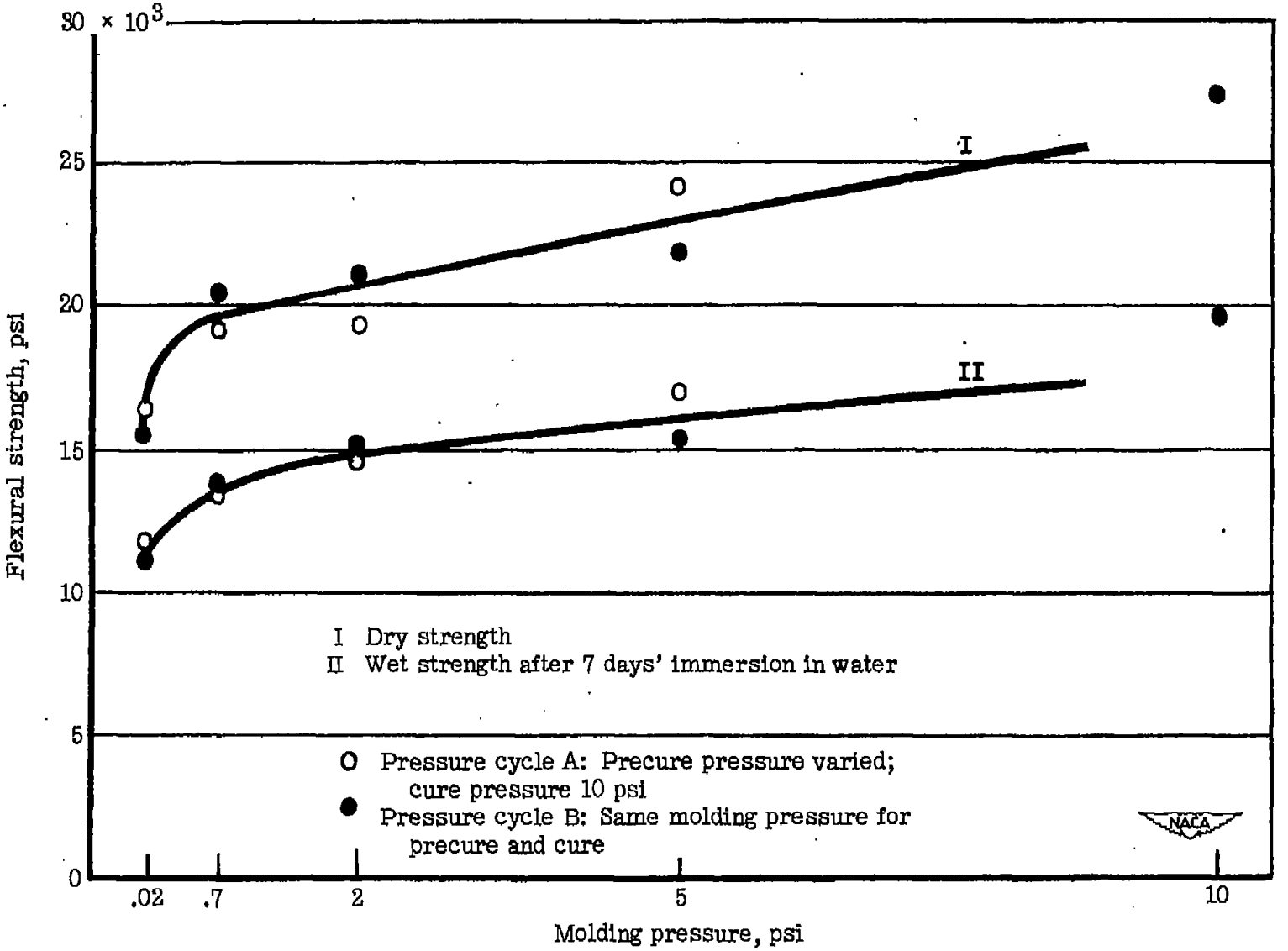

Figure 1.- Effect of molding pressure on flexural strength.

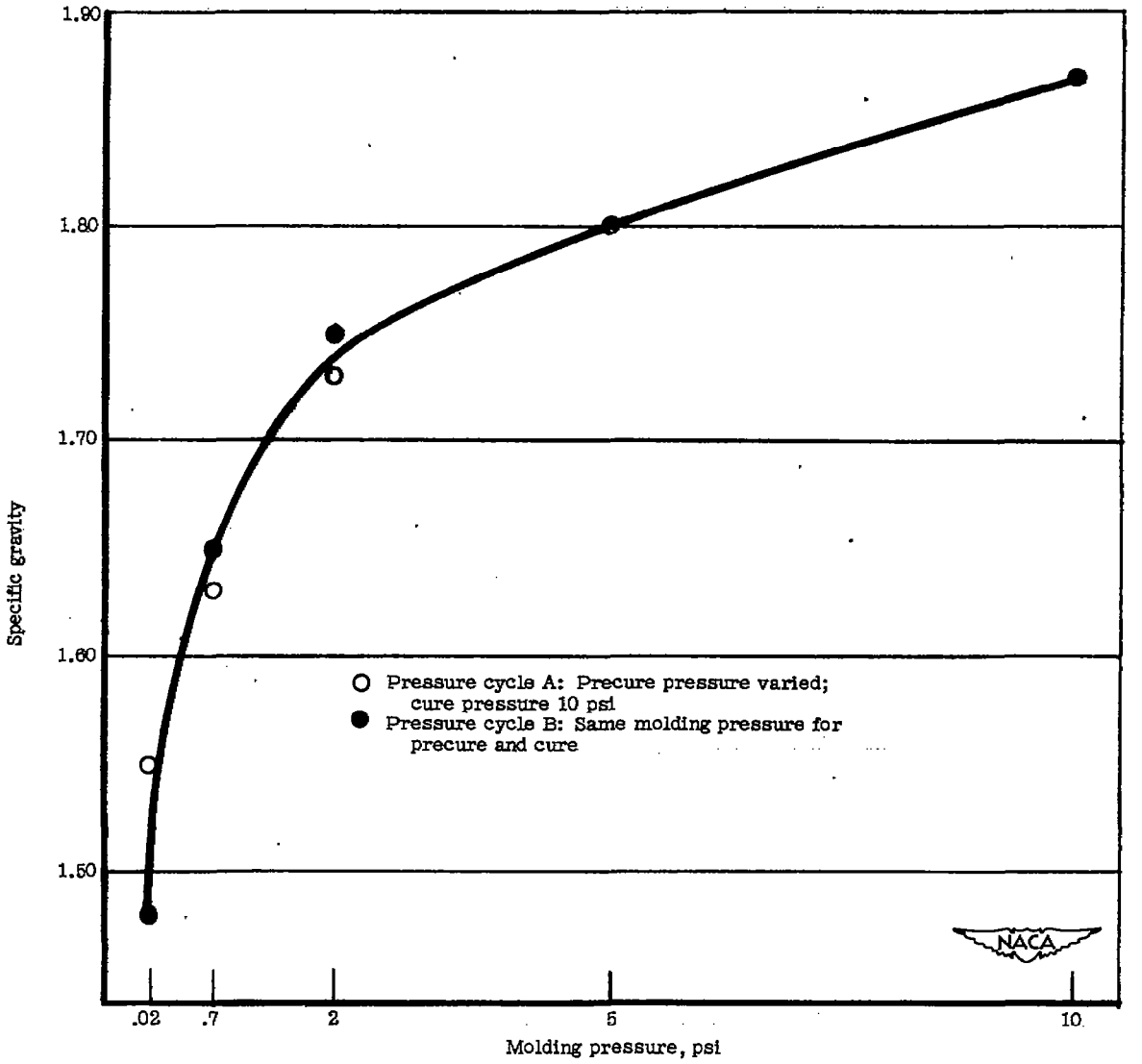

Figure 2.- Effect of molding pressure on specific gravity.

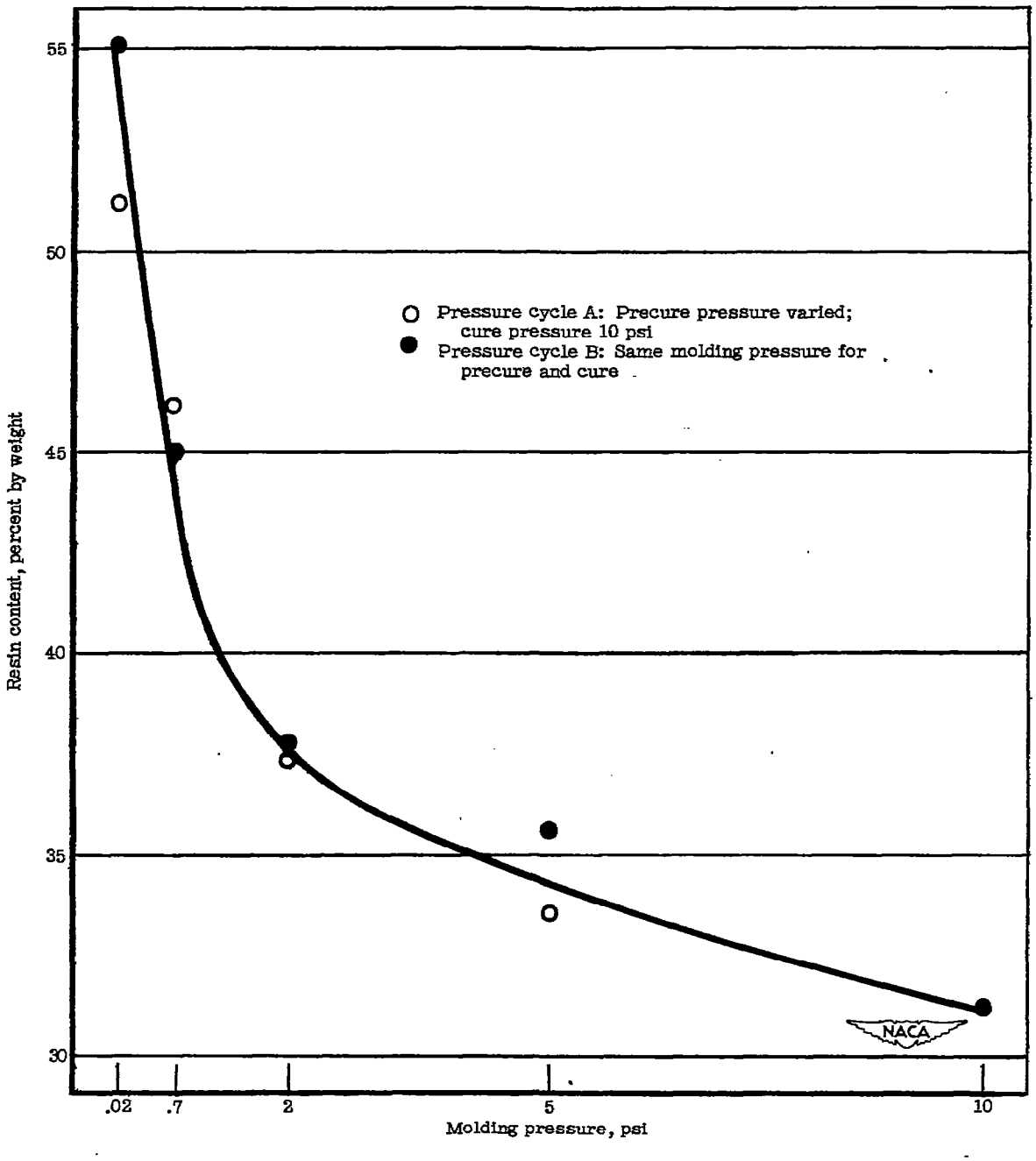

Figure 3.- Effect of molding pressure on resin content.

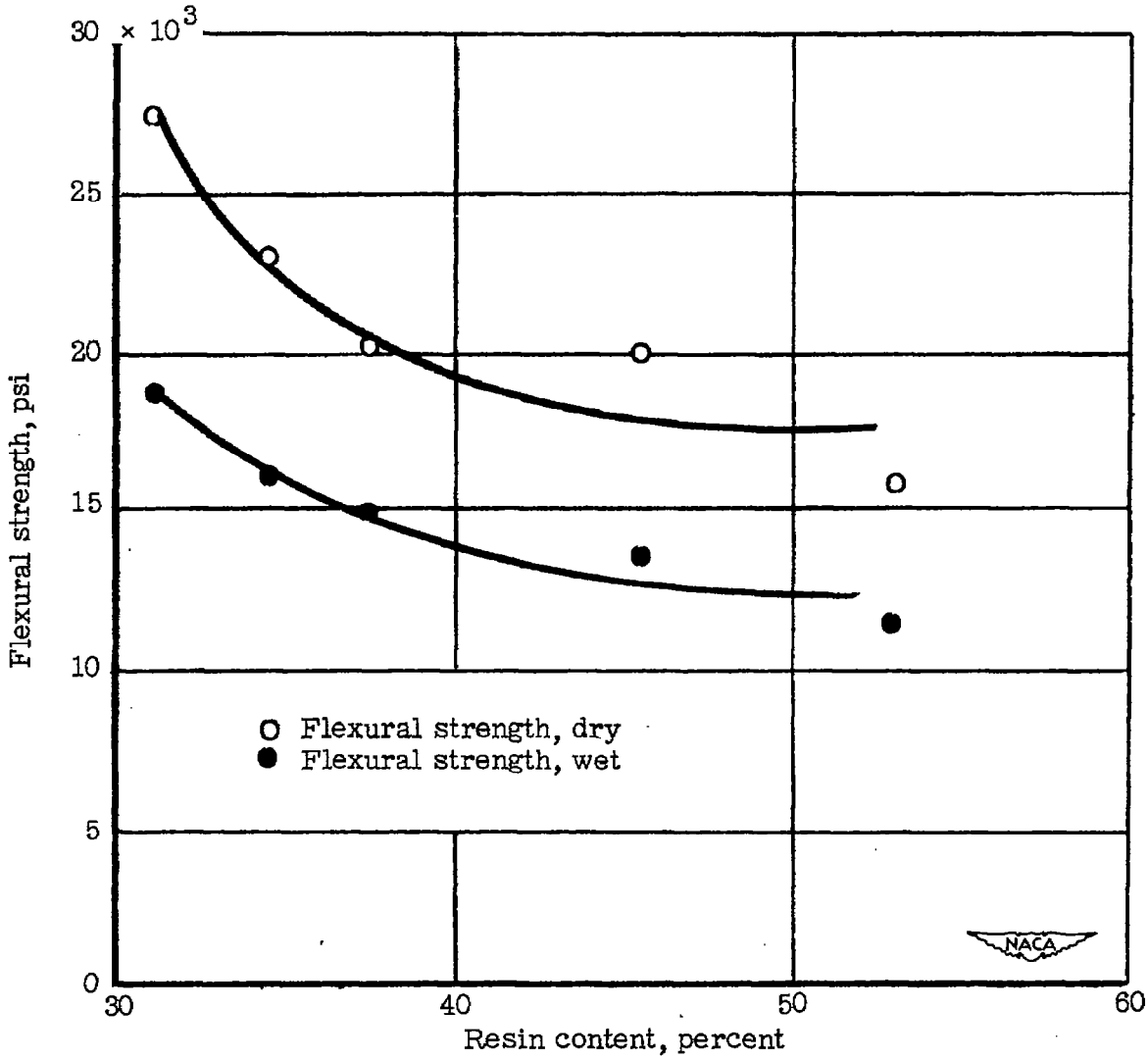

Figure 4.- Relationship between resin content and flexural strength.

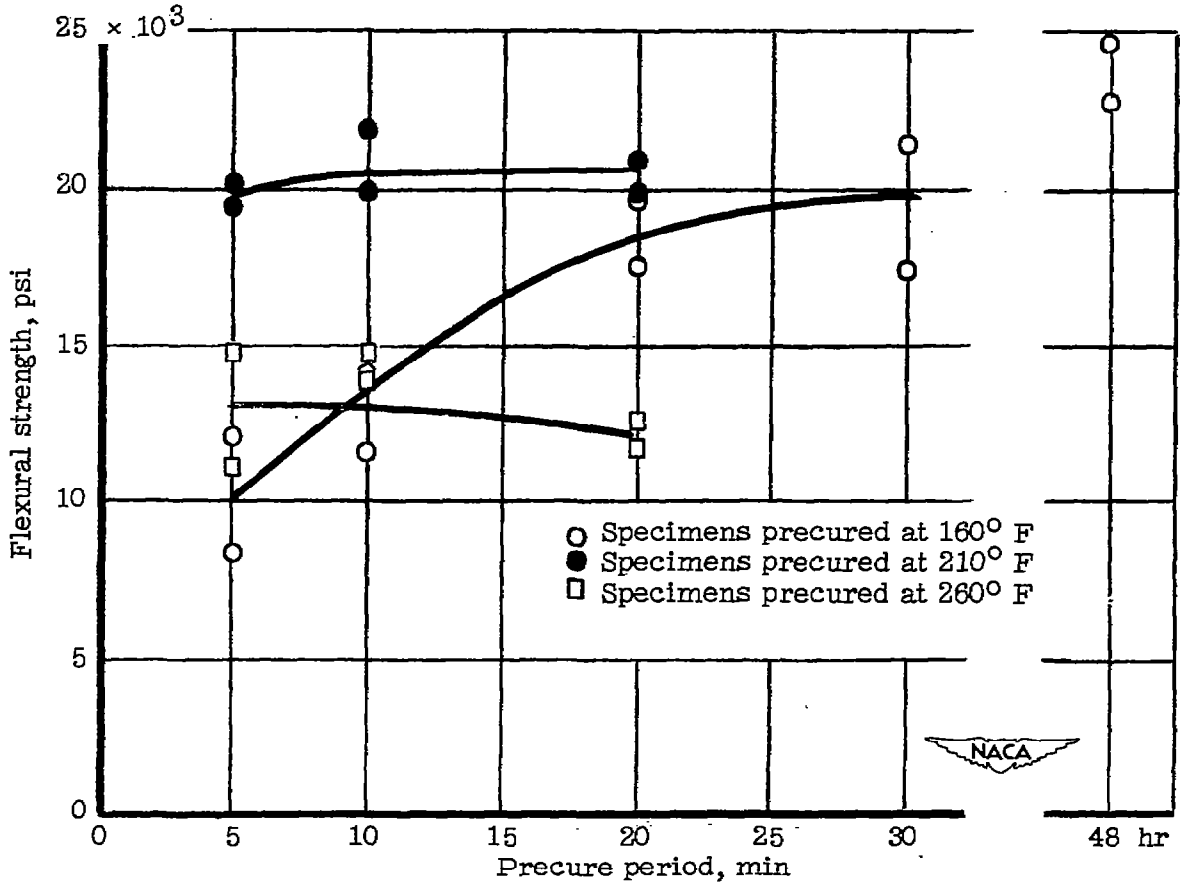

Figure 5.- Effect of variations in precure molding cycle on dry flexural strength.

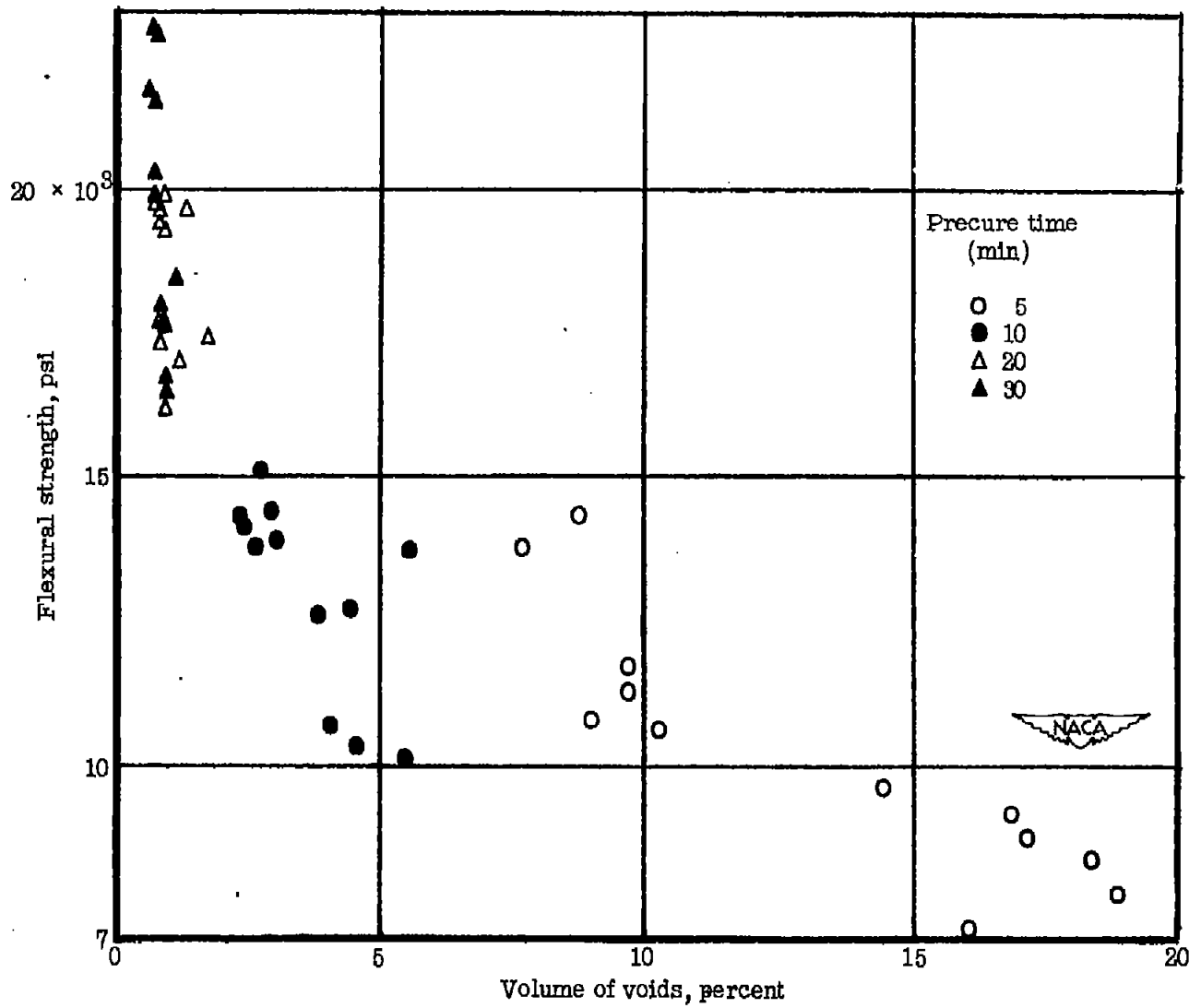

Figure 6.- Relationship between voids and dry flexural strength. Data for individual specimens of panels precured at 160° F for various periods of time.

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